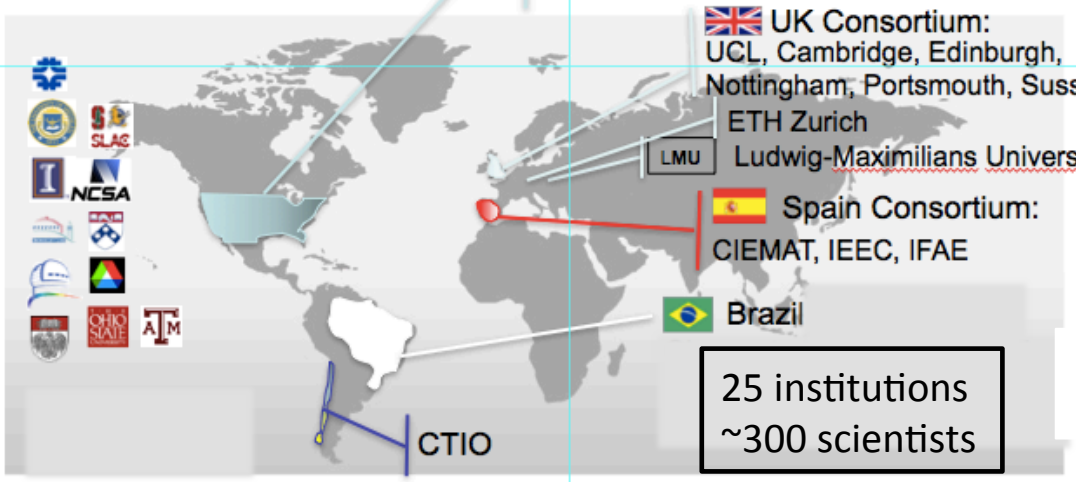
# Dark Energy Survey

**47th Fermilab Users Meeting, June 2014**

Marisa Cristina March
*on behalf of*
The Dark Energy Survey Collaboration

Funding from DOE, NSF, foreign funding agencies, and DES institutions

Fermilab, UIUC/NCSA, University of Chicago, LBNL, NOAO, University of Michigan, University of Pennsylvania, Argonne National Laboratory, Ohio State University, Santa-Cruz/SLAC/Stanford Consortium, Texas A&M




25 institutions
~300 scientists

Image credit: FNAL

THE DARK ENERGY SURVEY

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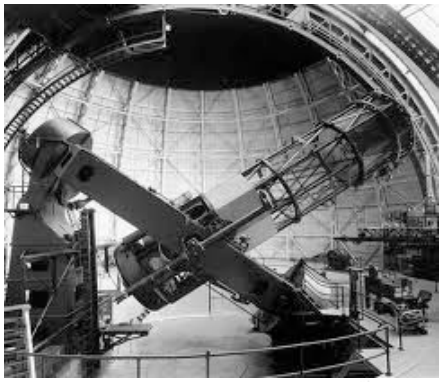
# Dark energy and cosmic acceleration

## Pre 1998: Hubble's expanding Universe



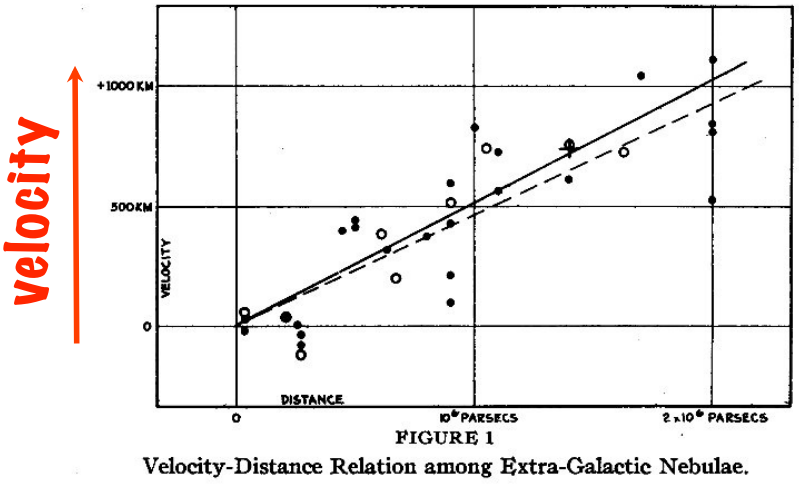



FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.

distance

## Post 1998: Accelerating Universe


Photo: Roy Kaltschmidt, Courtesy: Lawrence Berkeley National Laboratory
Saul Perlmutter


Photo: Belinda Pratten, Australian National University
Brian P. Schmidt


Photo: Homewood Photography
Adam G. Riess

2011 Nobel Prize in Physics: Acceleration!

**"nothing short of a revolution in our understanding of fundamental physics will be required to achieve a full understanding of the cosmic acceleration. …. the nature of dark energy ranks among the very most compelling of all outstanding problems in physical science …. demand an ambitious observational program to determine the dark energy properties as well as possible."** *(Dark Energy Task Force, June 2006 )*

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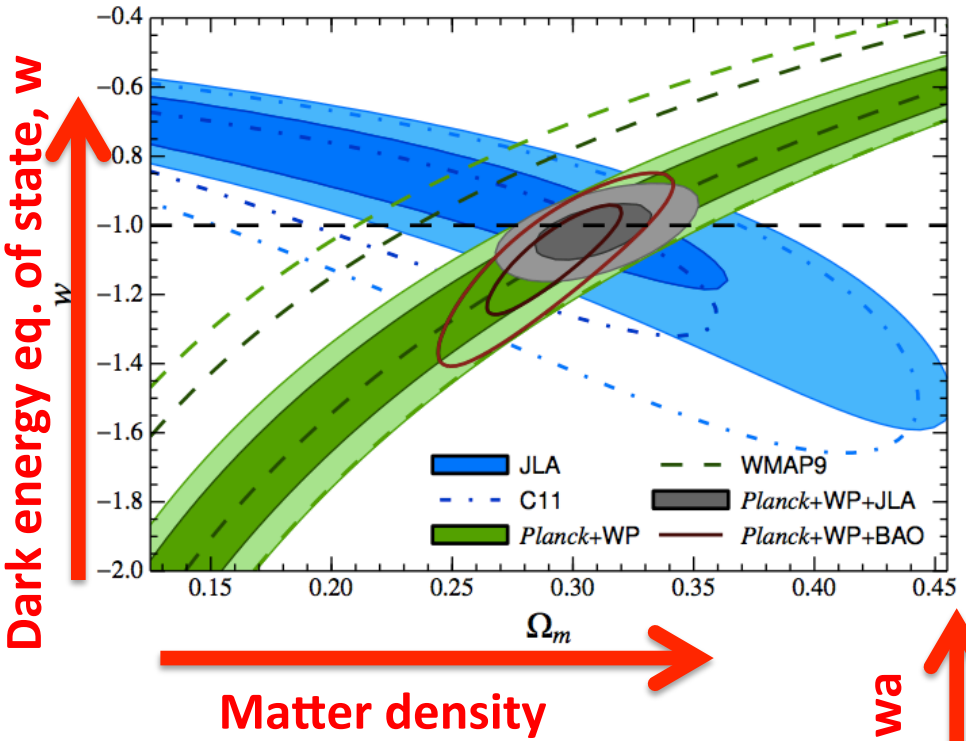
# Dark energy parameters and current combined constraints



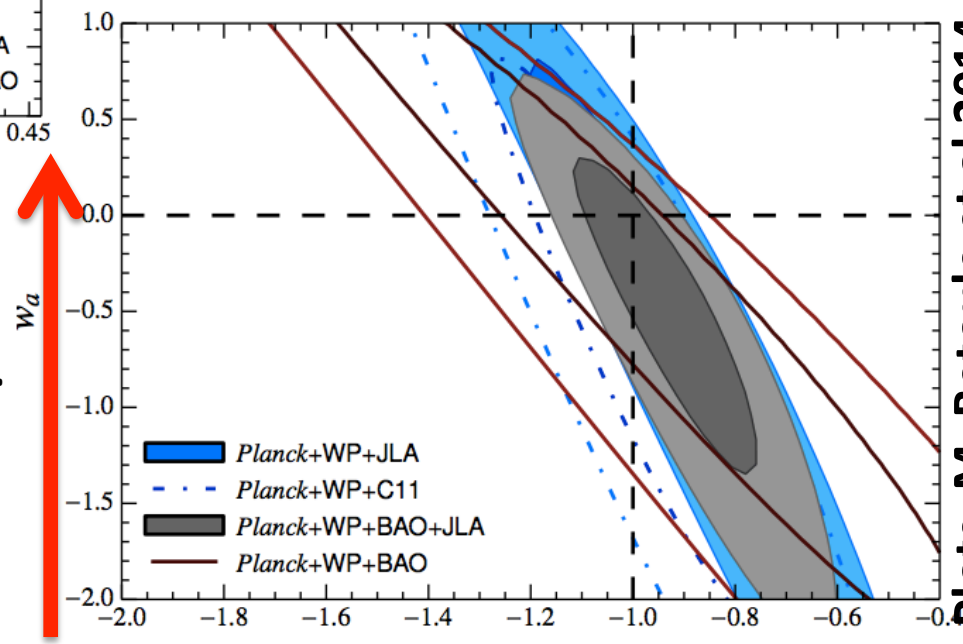

Matter density

**Dark energy equation of state:**

- **Ratio of dark energy pressure to density.**
- **Does w evolve with redshift?**

$$w = \frac{p}{\rho}$$

$$w(z) = w_0 + w_a \frac{1}{(1+z)}$$




Plots: M. Betoule et al 2014

- **Dark energy is best constrained by combining different types of observations.**
- **What is best dark energy model?**
- **Dark energy or modified gravity?**
- **Cosmological constant?**

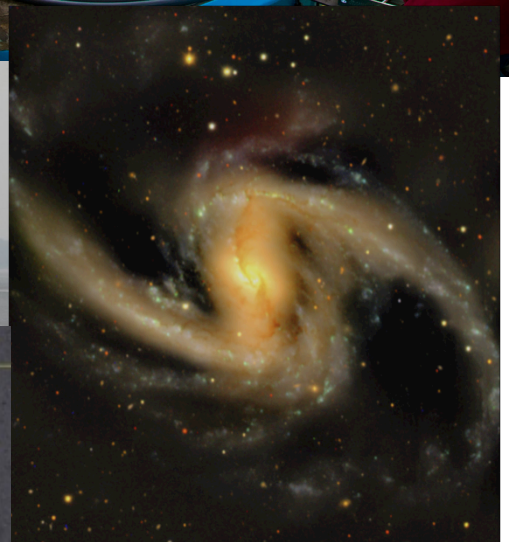
THE DARK ENERGY SURVEY

# A biography of the Dark Energy Survey

| | |
|---|---|
| **1998** | Discovery of Universal acceleration – dark energy? |
| **2003** | DECam and the Dark Energy Survey (DES) proposed. |
| **2008** | DECam and DES approved. |
| **2008-12** | Construction of parts. |
| **2010-11** | Shipping of parts to the telescope at CTIO in Chile. |
| **2010-12** | Assembly at telescope. |
| **Sept 2012** | First Light – Science Verification commences. |
| **Sept 2013** | Year 1 of survey begins. |
| **Aug 2014** | Year 2 of survey begins. |







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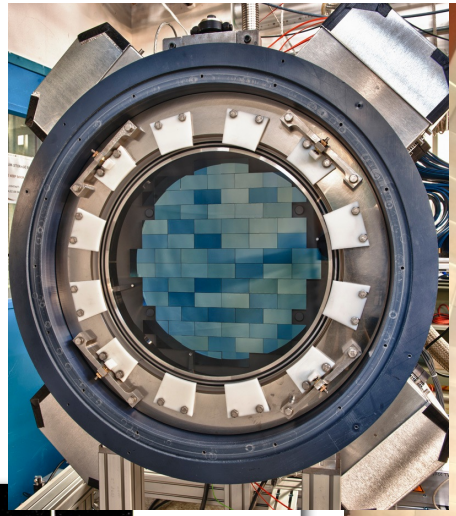
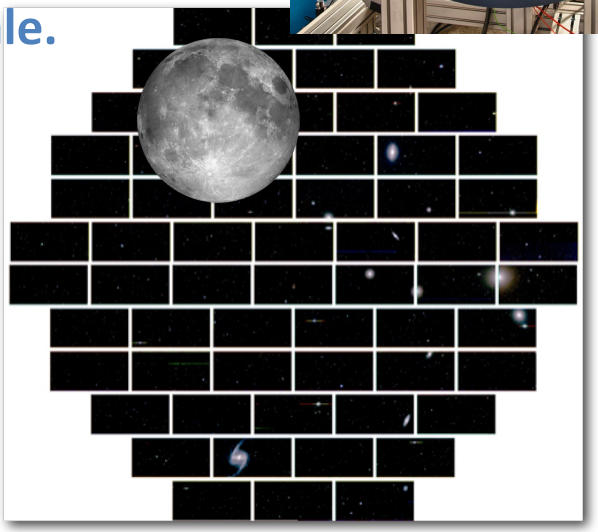
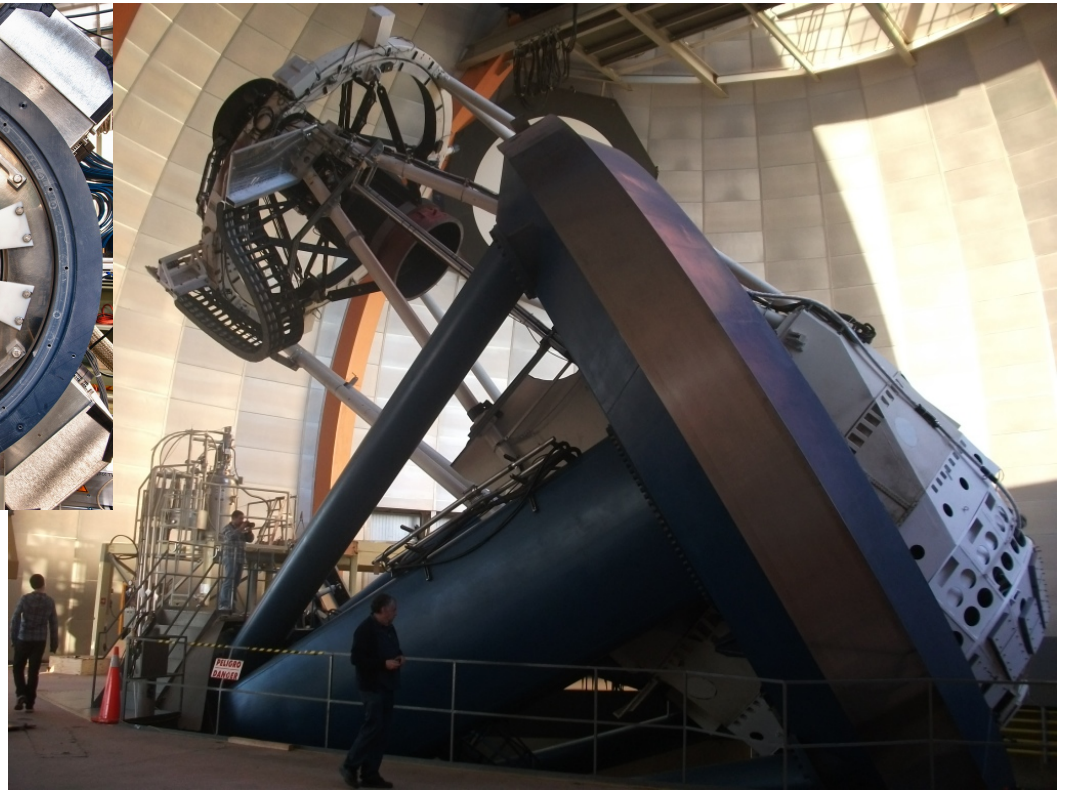
# Dark Energy Camera: DECam

**Right:** Dark Energy Camera focal plane.
**Below:** Single DECam image with moon superimposed to scale.







DECam: mounted on the Blanco telescope

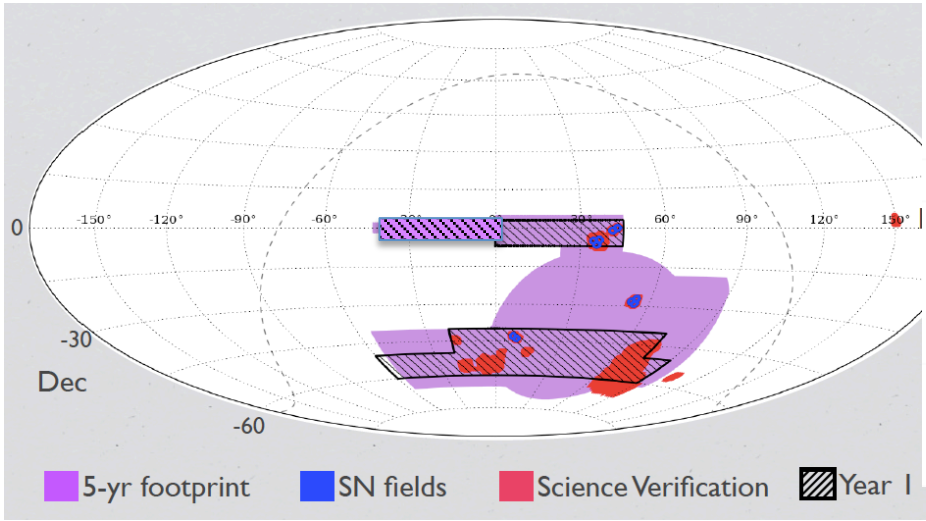
The 570 megapixel Dark Energy Camera was built to carry out an imaging survey to probe the nature of dark energy. The aim is to move from dark energy discovery to precision measurements of dark energy.

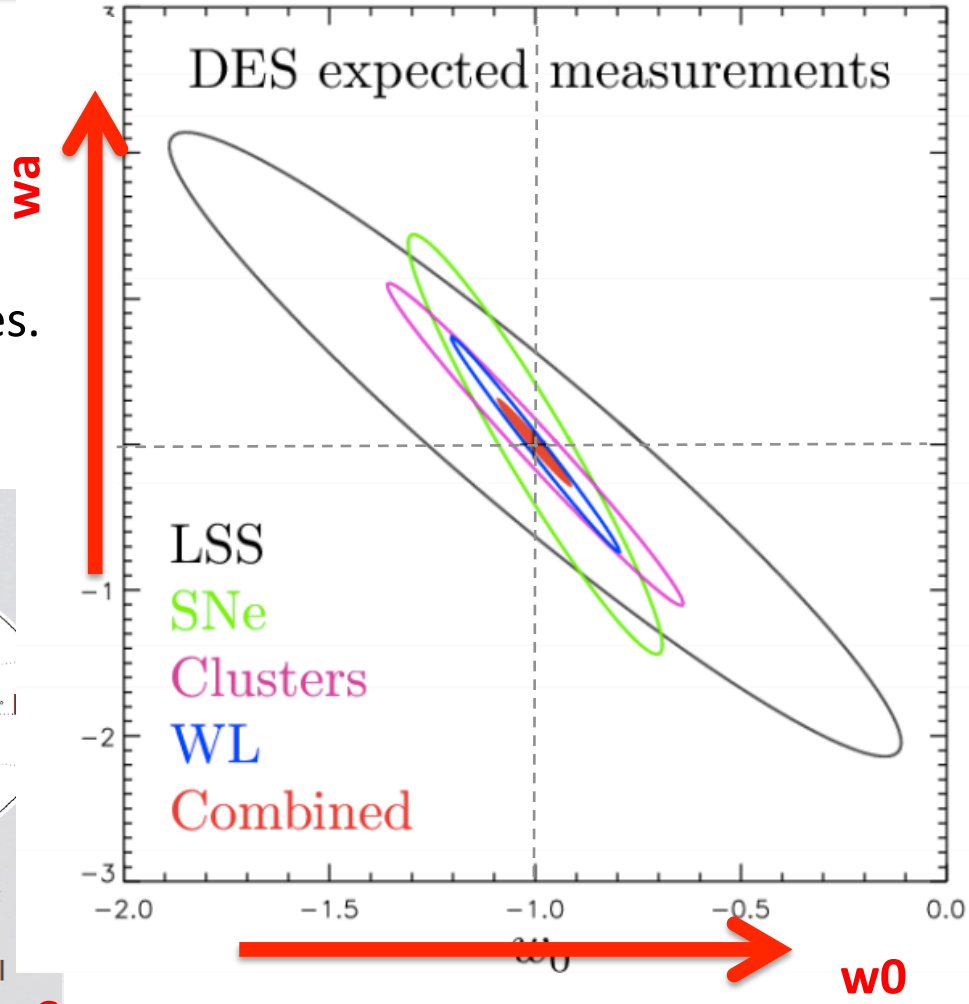
THE DARK ENERGY SURVEY

# Dark Energy Survey (DES)

DES is investigating the nature of dark energy using four different types of measurements:

1. Supernovae type Ia
2. Weak gravitational lensing of galaxies.
3. Large Scale Structure.
4. Galaxy cluster measurements.




**Survey:**

- 5000 square degrees
-525 nights over 5 seasons.
-10 supernovae fields.

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# Using standard candles to measure dark energy

**If you have objects of a standard brightness, you can work out how far away they are based on how bright they appear to be.**

Define the 'observed' distance modulus, to be the difference between the apparent (observed) and absolute magnitudes (brightness) of your standard object:

$$\mu^{\text{observed}} = m_B - M_0$$

$m_B$: apparent magnitude; $M_0$: absolute magnitude

The theoretical distance modulus depends on the redshift and the cosmological parameters:

$$\mu^{\text{theory}} = f\{z, \Omega_m, \Omega_\kappa, \Omega_\Lambda, w(z)\}$$

- $z$: redshift
- $\Omega_m$: matter density
- $\Omega_\kappa$: curvature density
- $\Omega_\Lambda$: dark energy density
- $w(z)$: dark energy equation of state

**Recipe:**

(1) Measure the apparent magnitude.
(2) Measure the redshift.
(3) Work out what values the cosmological parameters must be to get:

$$\mu^{\text{theory}} = \mu^{\text{observed}}$$

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# Using supernovae type Ia as standard candles

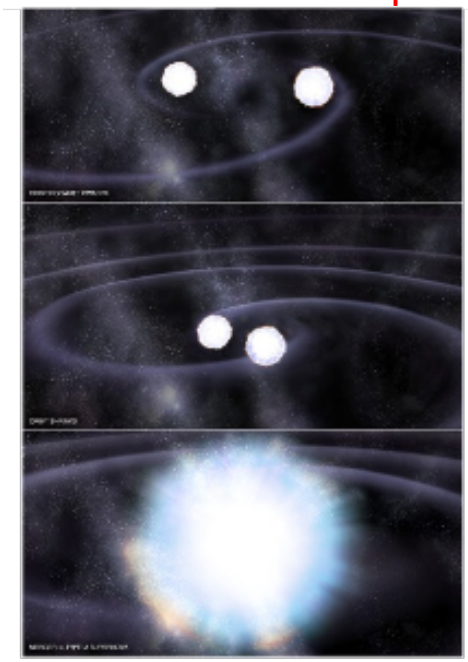
**We use the stretch and color of the SNe light curves to apply small corrections to (i.e. to standardize) their brightness.**

$$\mu^{\text{observed}} = m_B - M_0 + \alpha x_1 - \beta c$$

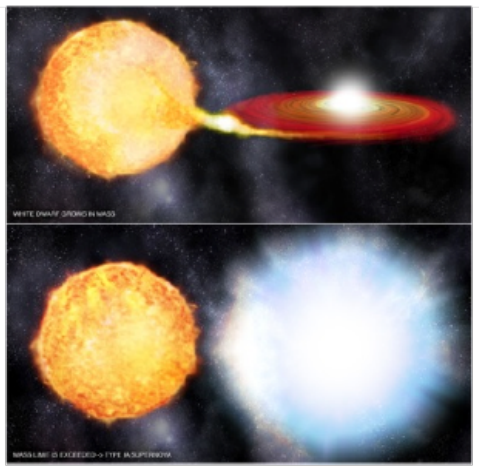
stretch

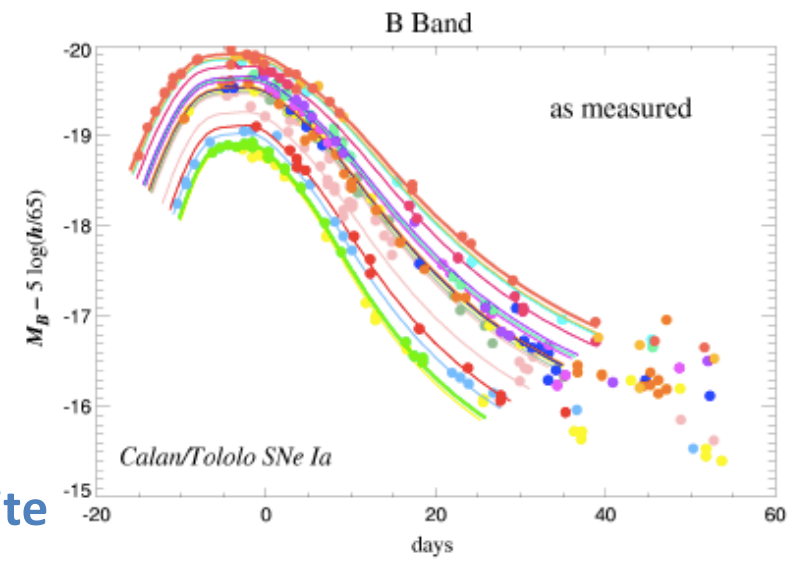
color

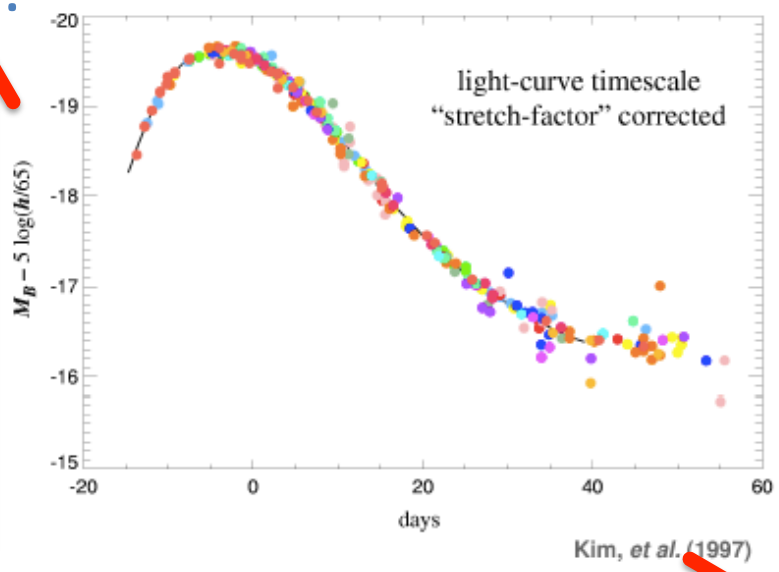
nuisance parameters



**SNe Ia thermonuclear explosions come from white dwarf binary mass transfer.**






magnitude

days

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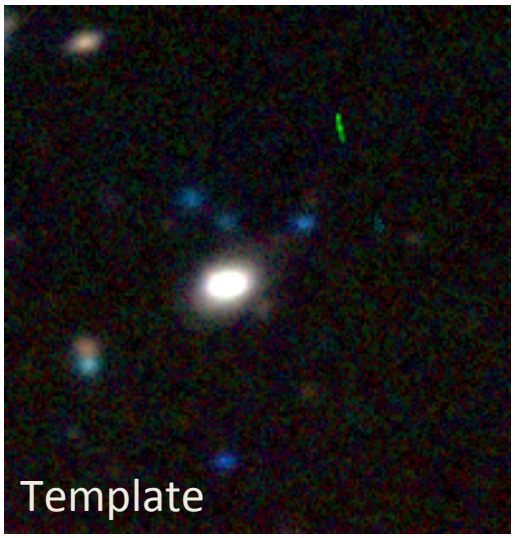
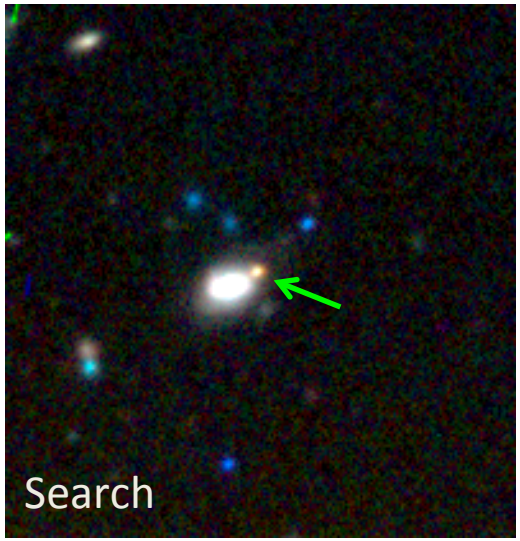
# Type Ia supernovae search with DES

**SNe Survey operations:**

1. Before survey, make 'templates'.
2. During survey, visit each SNe field a minimum of once every seven days.
3. Subtract the 'template image' from the new 'search image' and look for SNe candidates using human scanning and machine learning.
4. Classify candidates using a light curve photometric typer.
5. Monitor pipeline by injecting fake events.
6. Follow up ~10% of SNe Ia candidates spectroscopically. Follow up all host galaxies at a later date to get a spectroscopic redshift. (Non DES instruments)




First SN confirmed by DES, z =0.2 (AAT)

**Expected yield: ~4000 SNe to be discovered over 5-years.**

**Challenge: Photometrically classifying SNe Ia without SN spectra.**

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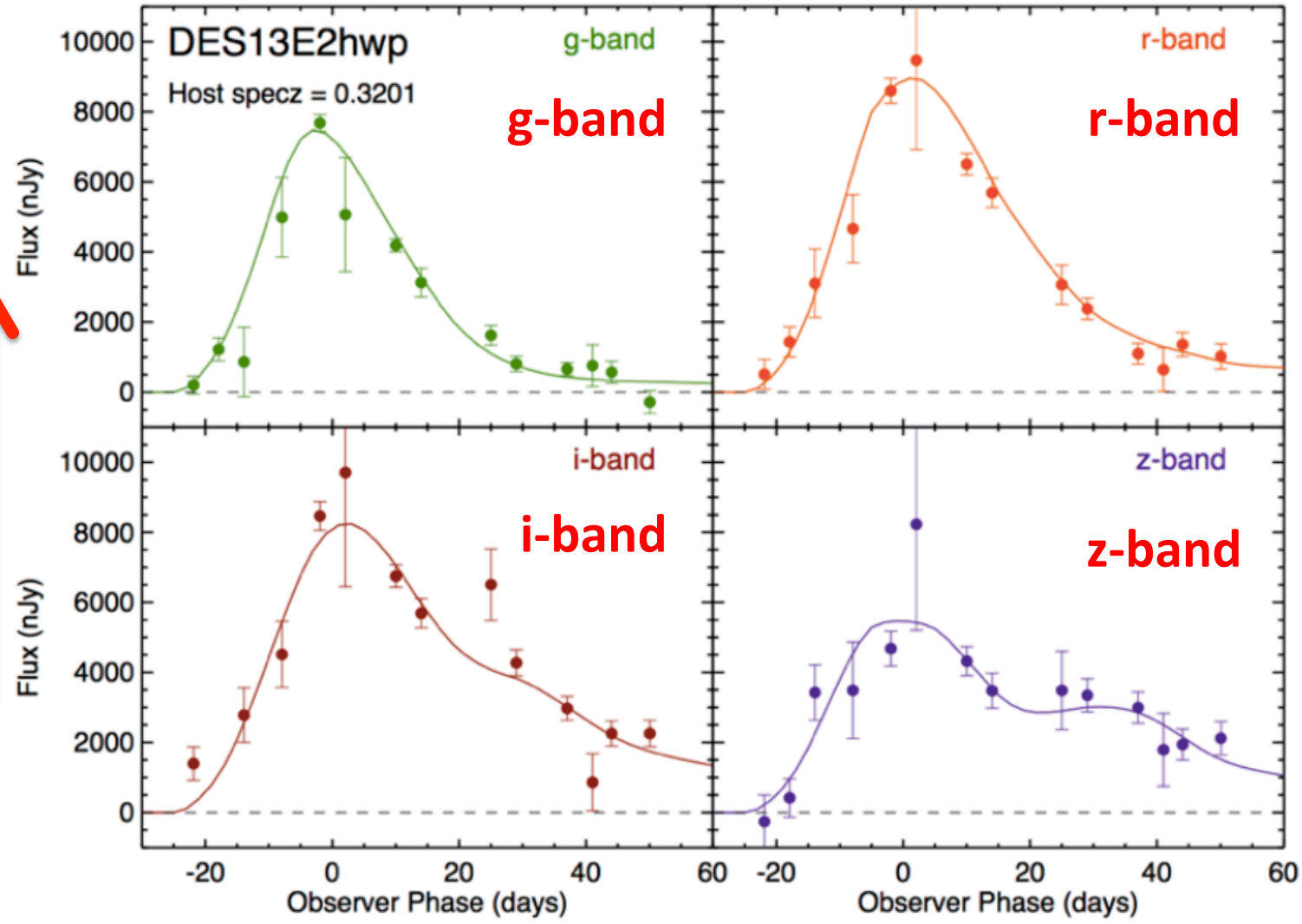
# A shallow field DES light curve z=0.32




Flux

Days

Data points: search photometry from subtracted DES images.

Solid lines: Fit to SALT2 light curve model.

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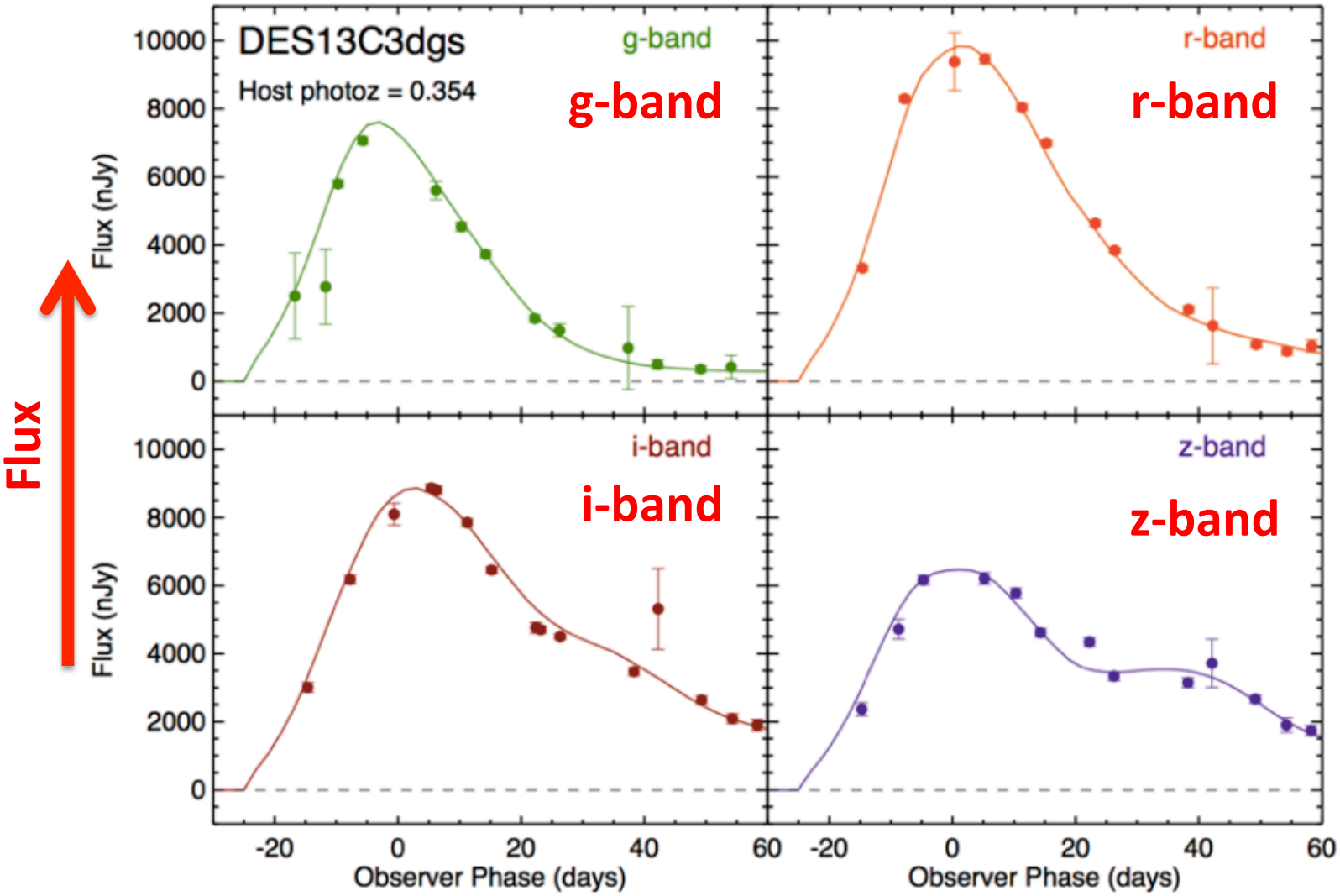
Graphics: C. D'Andrea, ICG Portsmouth

# A deep field DES light curve z=0.35




Data points: search photometry from subtracted DES images.

Solid lines: Fit to SALT2 light curve model.

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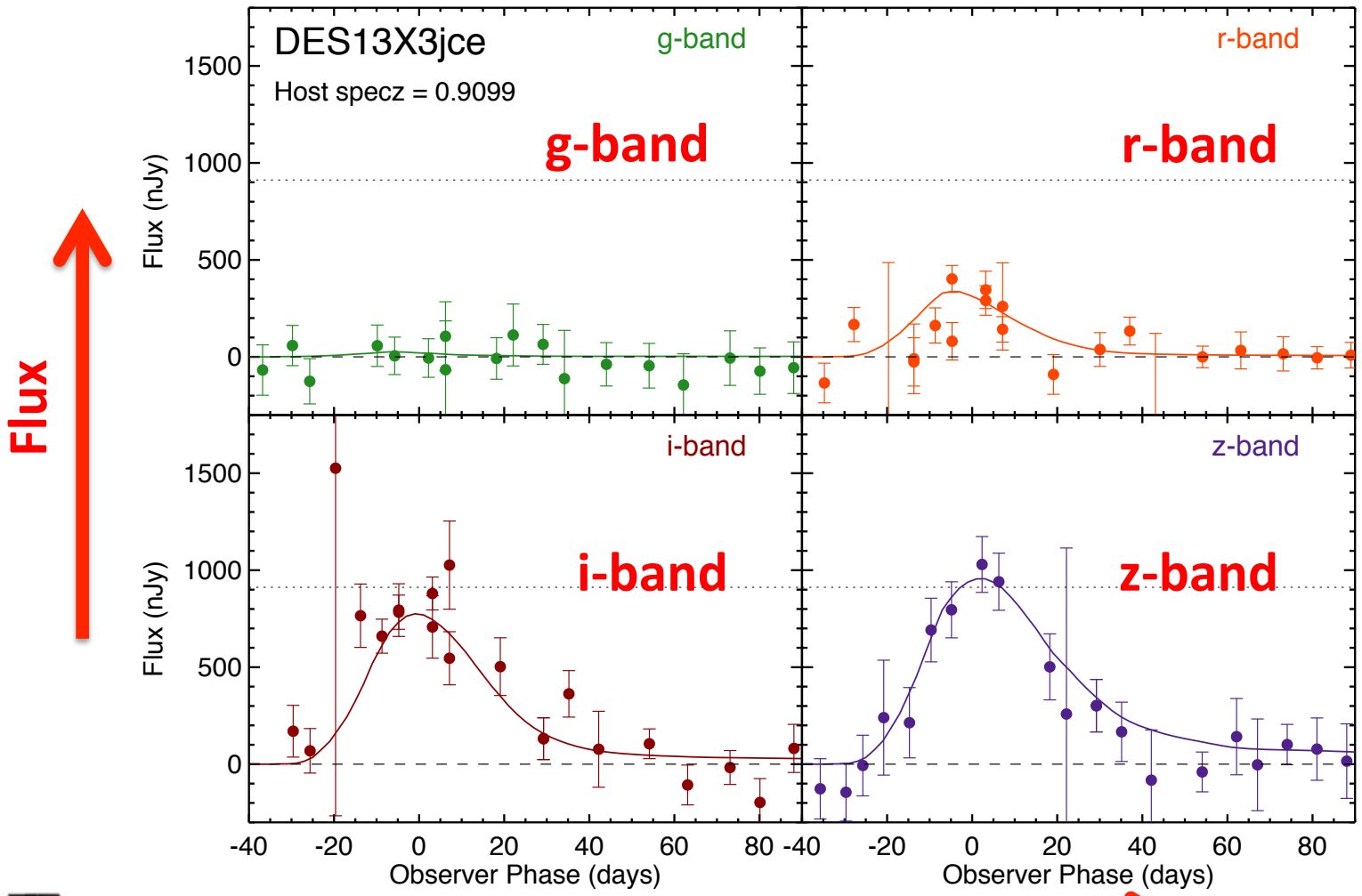
Graphics: C. D'Andrea, ICG Portsmouth

# A high redshift DES light curve: z=0.9

**[Deep field]**




**Data points: search photometry from subtracted DES images.**

**Solid lines: Fit to SALT2 light curve model.**

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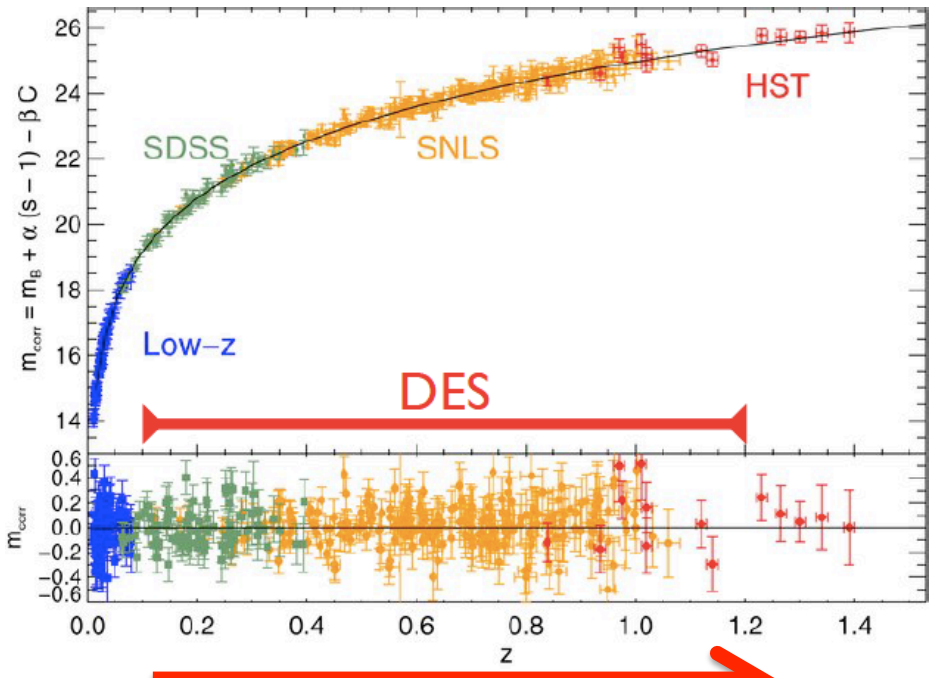
Graphics: C. D'Andrea, ICG Portsmouth

# Pre-DES

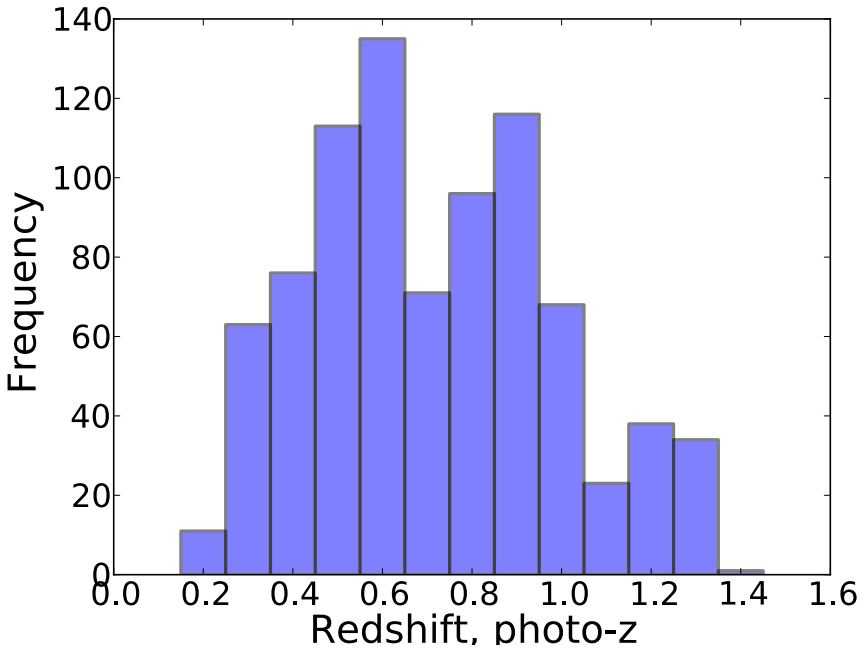



Conley et al 2011 (adapted)

**Redshift, z**

- Above Hubble plot is from a compilation of 475 SNe Ia from four different surveys. (Current largest compilation uses ~800 SNe Ia)

# 1st year DES

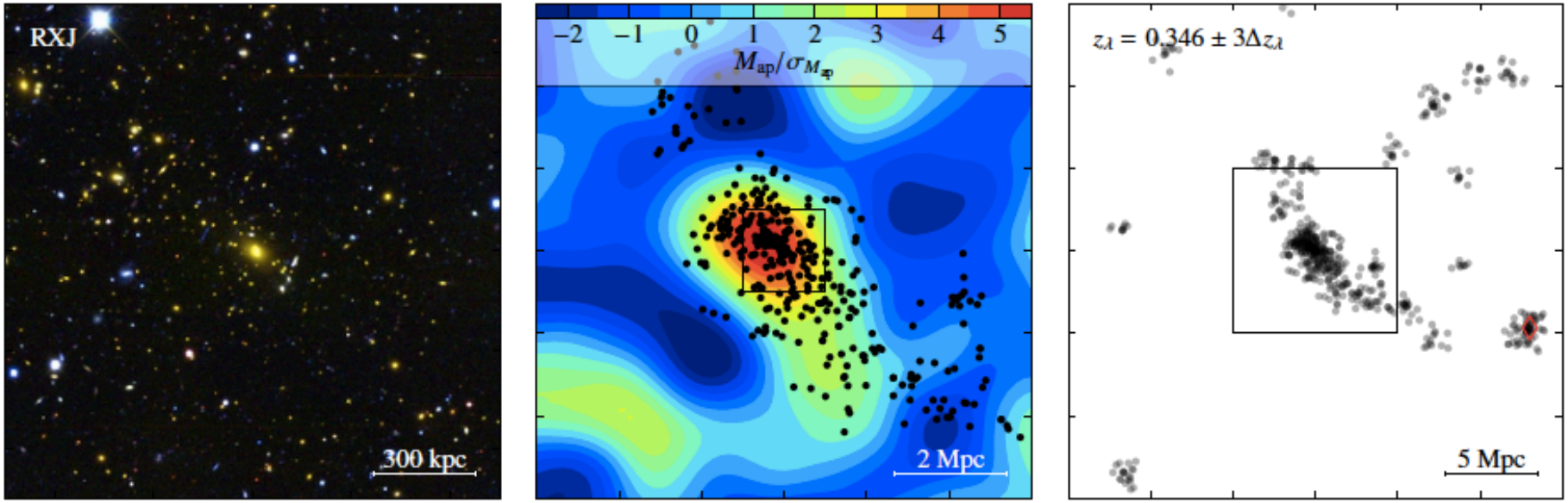



**Redshift, z**

- 1st Year DES SNe survey yielded ~800 Sne type Ia light curves that pass selection and quality cuts.
- Expected 5 year yield: ~3500 SNe type Ia.

# Galaxy clusters & tests of analysis methods

**Optical DECam image** | **Weak lensing mass contours** | **Cluster members**

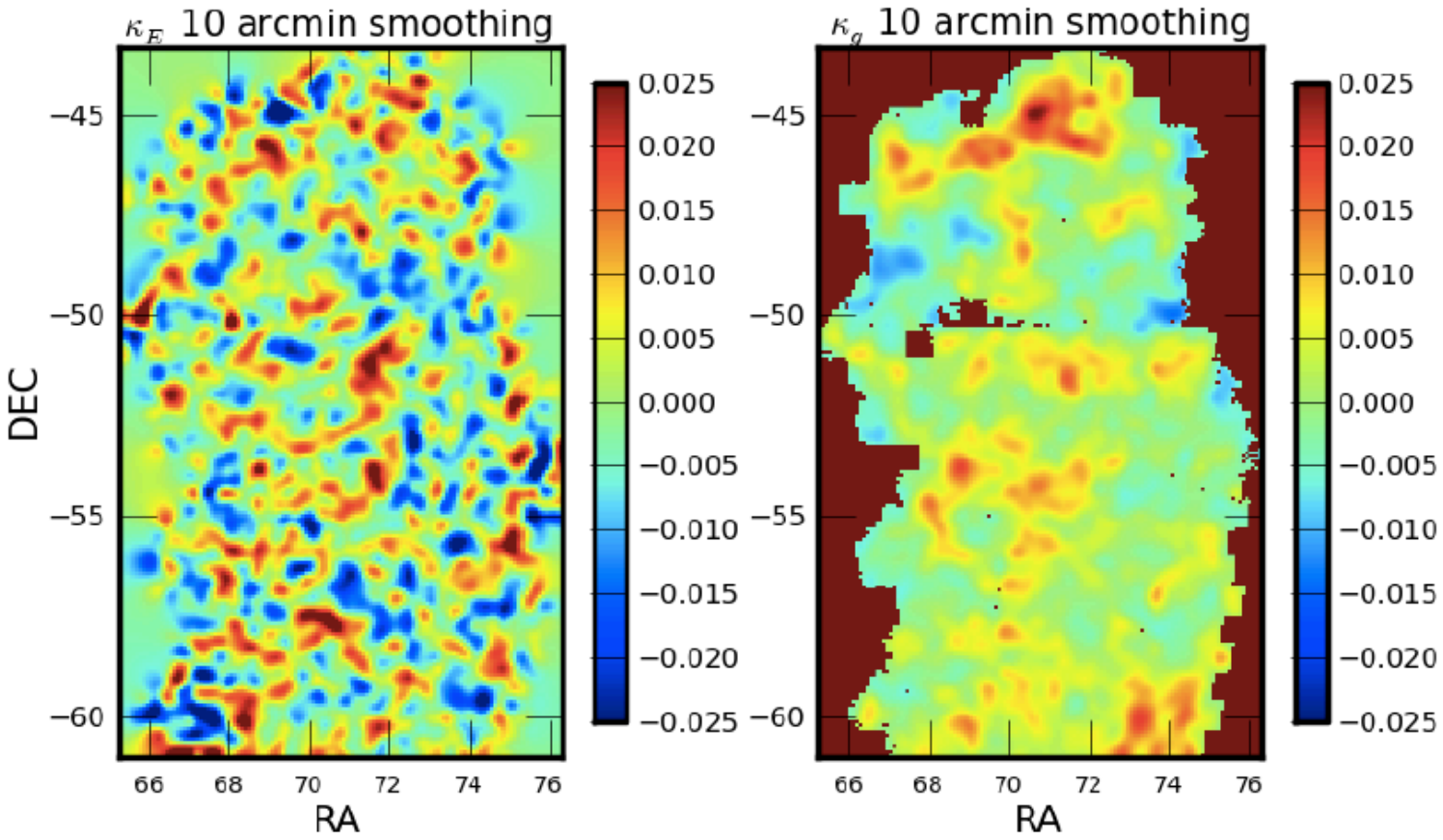



Melchior et al 2014, arxive: 1405.4285

- **Background galaxies identified using photometric redshifts (photo-z).**
- **Cluster member galaxies identified using photometry & redMaPPer algorithm.**
- **Test of weak lensing algorithm Im3shape with DECam images.**
- **Good agreement between both mass mapping methods & also previous studies.**

# First wide field weak lensing analysis

V. Vikram et al, in prep




**Weak lensing mass map (Uses background galaxies)**

**Foreground galaxies – tracers of matter.**

**Weak lensing and foreground are correlated at a statistically significant level → Good check of weak lensing technique**

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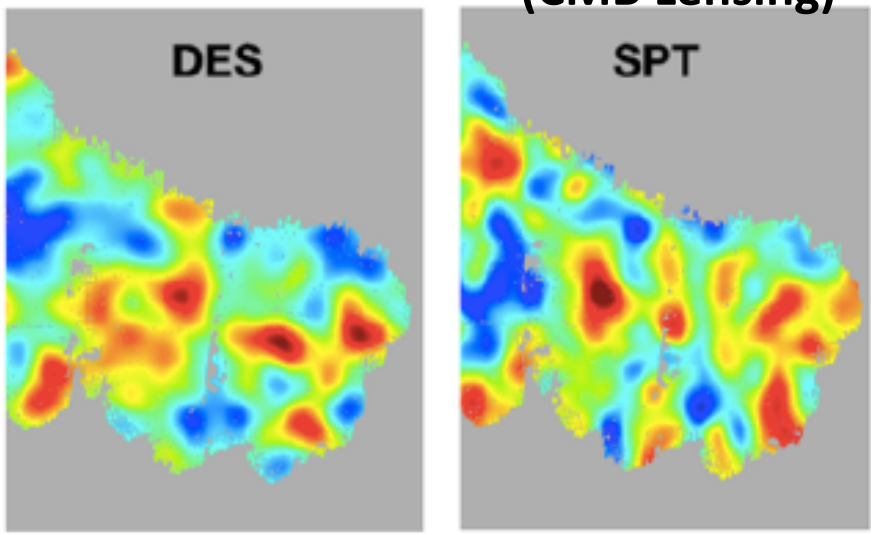
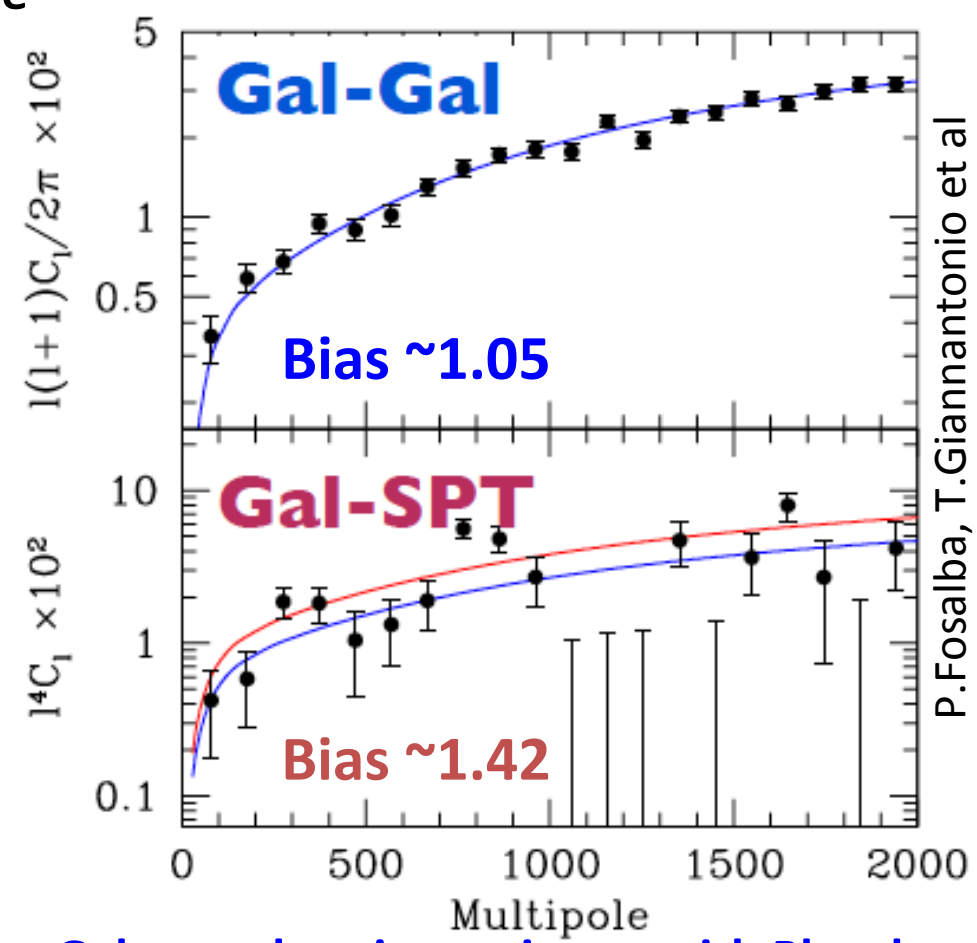
# Large scale structure: galaxies & CMB lensing

**South Pole Telescope (CMB Lensing)**




[P. Fosalba]




- **Galaxy-galaxy correlation function probes cosmology.**
- **CMB Lensing is a potential future dark energy probe.**

- **Galaxy-galaxy is consistent with Planck.**
- **Galaxy-CMB Lensing is consistent with galaxy-galaxy correlation function**

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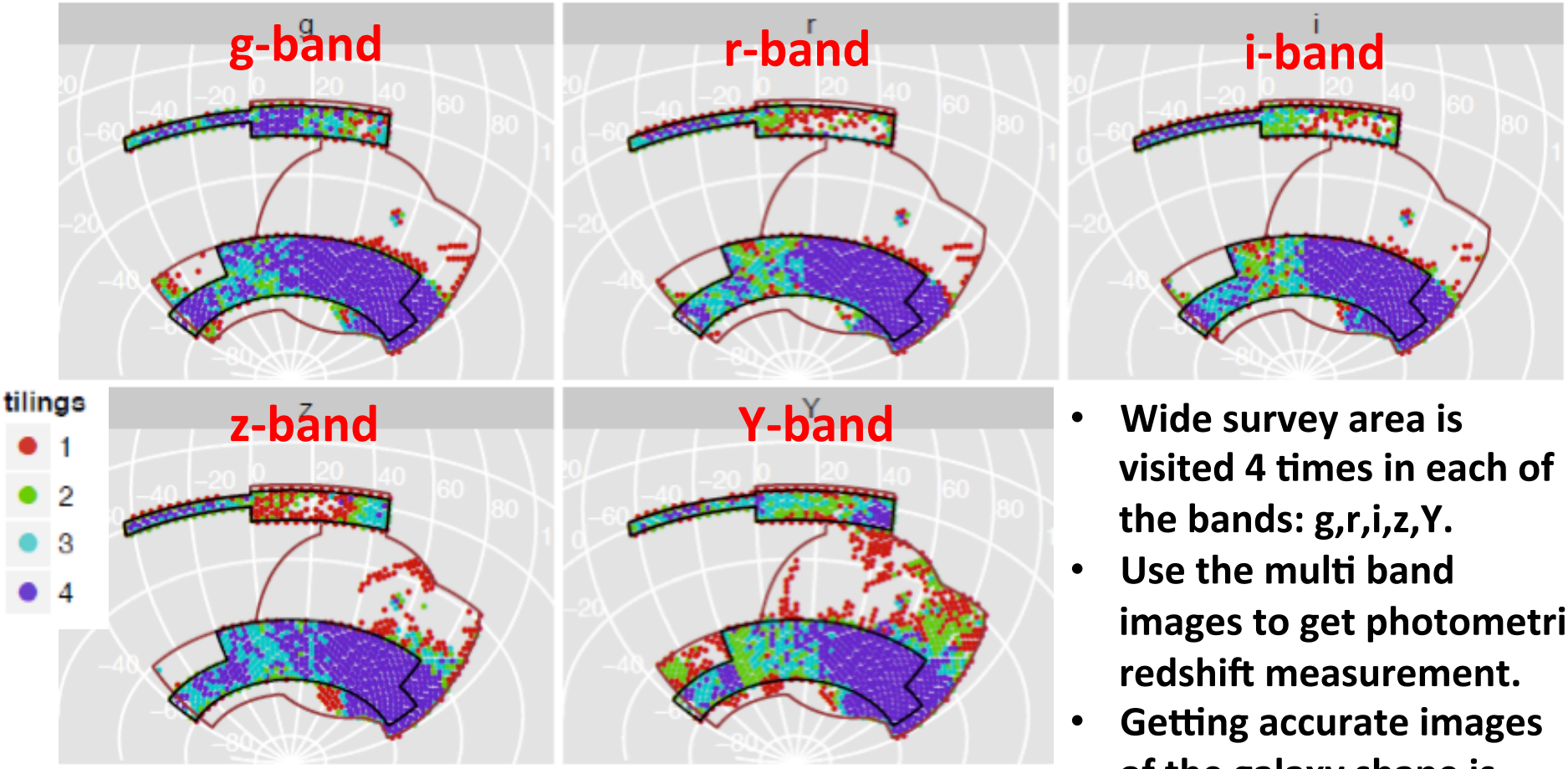
# Year 1 wide survey progress




- **Wide survey area is visited 4 times in each of the bands: g,r,i,z,Y.**
- **Use the multi band images to get photometric redshift measurement.**
- **Getting accurate images of the galaxy shape is critical for weak lensing measurement.**

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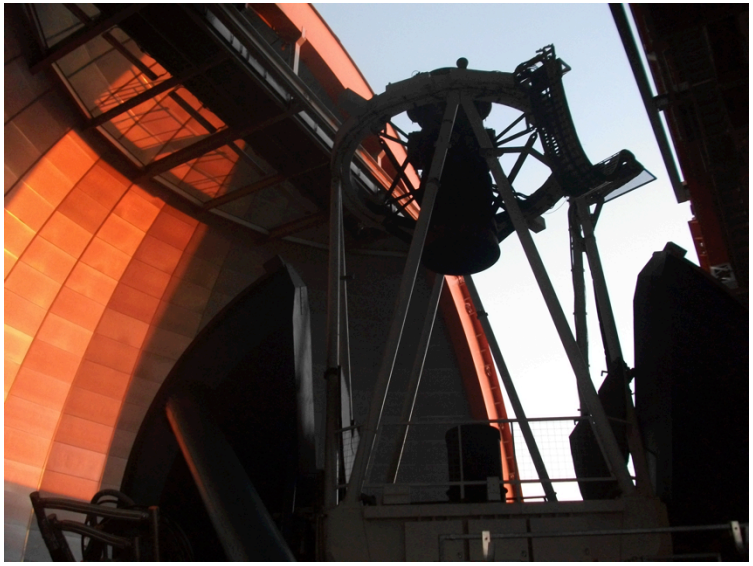
# DES at the end of year 1.

**Feb 2014 saw the conclusion of a successful year 1 observing season. Y2 begin August 2014!**

**Look out for these upcoming papers based on SV & Y1 data:**

- Discovery and properties of a Superluminous SN at high redshift
- Orientation Bias of Optically Selected Galaxy Clusters and its Impact on Stacked Weak Lensing Analyses
- Crowded Cluster Cores: Algorithms for Deblending in DES Images
- Photometric Redshifts in the DES SV Data Set
- Joint Optical and Near Infrared Photometry from the DES and VHS
- Mass and Cluster Galaxy Distributions of Massive Clusters in DES SV Data
- DES: Redshifts, X-ray Temperatures, and Luminosities for Clusters in SV Data
- Galaxy-galaxy Lensing with DES SV Data
- Wide-Field Mass Mapping with DES SV Data
- Galaxy Populations and Stellar Mass Fractions in SZE-selected Clusters Imaged by the DES



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